Applied Occupational and Environmental Hygiene
Volume 17(2): 88–95, 2002
1047-322X/02 $12.00 + .00

PDF

Evaluation of Concurrent Personal Measurements of Acrylonitrile Using Different Sampling Techniques

John N. Zey,[1] Patricia A. Stewart,[2] Richard Hornung,[3] Robert Herrick,[4] Charles McCammon,[6] Dennis Zaebst,[5] Linda M. Pottern,[7] Mustafa Dosemeci,[2] and Thomas F. Bloom[5]

[1]Department of Safety Science and Technology, Central Missouri State University, Warrensburg, Missouri; [2]National Cancer Institute, Rockville, Maryland; [3]Institute for Health Policy and Health Services Research, University of Cincinnati Medical Center, Cincinnati, Ohio; [4]Department of Environmental Health, Harvard University, Boston, Massachusetts; [5]National Institute for Occupational Safety and Health, Cincinnati, Ohio; [6]Tri-County Health Department, Commerce City, Colorado; [7]Office of Disease Prevention, National Institutes of Health, Bethesda, Maryland

In a retrospective assessment of employee exposure to acrylonitrile (AN) for an epidemiological study, investigators from the National Cancer Institute (NCI) and the National Institute for Occupational Safety and Health (NIOSH) evaluated the feasibility of using historic acrylonitrile air samples without modification. The evaluation discussed here was to determine whether the air sampling results across plants were comparable. During site visits to each plant conducted between 1984 and 1986, study investigators collected personal air samples for four days on approximately ten jobs per day. During these visits, IHs at seven of the eight plants also collected personal samples to compare their sample values to the study-collected sample values. Each plant's IH collected these concurrent measurements for their own use and independent of the IHs at the other plants. The plant IHs had no common sampling protocol but, rather, used professional judgment in deciding sampling logistics for their concurrent measurement. In addition, each plant IH used a different laboratory to analyze samples (the study industrial hygienists used one laboratory). Three sampling methods were used by plant industrial hygienists to collect concurrent measurements: charcoal tubes, passive monitors, and porous polymer tubes. The study investigators only used charcoal tubes. Two hundred and sixty four (264) pairs of concurrent measurements were collected. To assess the +/− comparability of the data sets, paired-observation tests were used. The two sets of charcoal tubes were found to compare favorably with each other. The study's charcoal tubes were 1.2 times higher than results from plant passive monitors. No correlation was found between the study's charcoal tube results and plant porous polymer tube results, although the means for 34 pairs of samples were equivalent. As a result of this evaluation, the investigators decided that no adjustments would be made to the plant measurements. This type of evaluation should be considered when using measurement data in multisite epidemiological studies.

Keywords Acrylonitrile, Concurrent Measurements, Personal Samples, Field Sample Variability

Investigators of epidemiological studies use the presence of an exposure-response relationship as one criterion to evaluate causality. Exposure is usually described in terms of airborne exposure levels and assessment of these exposures is heavily dependent on the availability of air measurement data. In retrospective cohort studies, investigators generally cannot conduct air monitoring in the workplace(s) being studied using statistically valid sampling strategies to estimate exposures because most of the exposures occurred under conditions that are no longer present. As such, investigators are limited to using any historical data that are available, typically generated by the company being studied.(1)

One of the problems with using such data is that the sampling or analytical methods often changed over the period of the study. In such cases, investigators have compared measurement results taken concurrently with both the old and new methods to determine their comparability.(2) A conversion factor was then estimated to allow use of the older data.

In the study described in this article, the predominant problem was not that the sampling and analytic method changed over time, rather that there were eight companies in the study and each used their own sampling and analytical method. The problem

posed by this situation, however, is similar to that of changes in methods over time, that is, how to maximize the accuracy of the exposure measurements by using all the data available, yet reduce misclassification of the exposure estimates by making the measurement results as comparable as possible.

The authors took advantage of measurement data collected for different purposes to explore the comparability of the measurement data from the different plants. The purpose of this evaluation was exploratory only. Because of the need to use all the measurement data in the epidemiological study, the limitations of the data and the preliminary nature of this type of investigation, the authors did not believe that an accept/reject approach was appropriate. The goal of the evaluation was simply to provide information that would be useful to the interpretation of the epidemiological results. The purpose of this article is to highlight the problems of having measurement data from different work sites to develop exposure estimates for use in a single analysis.

BACKGROUND

In response to the suggestive evidence of the human carcinogenicity of acrylonitrile (AN), the National Cancer Institute (NCI) and the National Institute for Occupational Safety and Health (NIOSH) investigated the mortality experience of workers exposed to AN (hereafter referred to as the AN Study).[3] The AN Study, which began in 1984, included eight plants that started AN operations from 1952 to 1965. Previous mortality studies of acrylonitrile workers had incorporated no quantitative assessments of the workers' exposure to AN. To rectify this lack of information, quantitative assessments were developed in the AN study using systematic and documented procedures.[3–7]

The eight plants in the study produced AN monomer, acrylic fiber, acrylic resins, and other smaller volume AN-based products. Starting about 1978, all eight plants began collecting personal air monitoring data for AN. The majority of samples were collected in accordance with the Occupational Safety and Health Administration (OSHA) standard promulgated in 1978.[8] Each plant, however, used its own sampling and analytical method (Table I). Charcoal, whether in the form of a charcoal tube or a passive monitor, was the most frequently used collection medium. Desorption from the charcoal was accomplished using primarily carbon disulfide, methanol, or thermal desorption. Gas chromatography was the primary analytical technique. Although substantial numbers of measurements existed over time, the authors believed a limited monitoring effort, selecting jobs based on the needs of the epidemiological study, would be helpful. The original purpose for collecting personal samples was to supplement the existing monitoring company data.

TABLE I
Sampling and analytical methods used by acrylonitrile facilities

Plant ID (type)[A]	Time period method was used	Collection device[B]	Desorption solvent or technique[C]	Analytical technique[D]
1	1978–1980	CT	Methanol	GC
(Fib)	1980–1987	PM	CS_2	GC
2	1977–1978	PP	Thermal	GC
(Mon)	1978–1987	PM	CS_2	GC
3	1978–1987	CT	CS_2	GC
(Mon)				
4	1970–1977	Bubbler	Permanganate	Titration
(Fib)	1977	CT	CS_2	GC
	1977–?	PM	CS_2	GC
	?–1987	PM	Methanol	GC
5	1978–1980	CT	CS_2	GC
(Fib)	1980–1987	PM	CS_2 + 2% Ace	GC
6	1977–1981	CT	Methanol	GC
(Mon)	1981–1987	PM	Methanol	GC
7	1977	CT	CS_2	GC
(Res)	1977–1987	PP	Thermal	GC
8	1977–1979	PP	Thermal	GC
(Mon)	1979–1987	PM	CS_2	GC

[A]Mon = Monomer Plant; Fib = Fiber Plant; Res = Resin Plant.
[B]CT = Charcoal Tube; PM = passive monitor; PP = porous polymer.
[C]CS_2 = Carbon Disulfide; Ace = acetone.
[D]GC = Gas Chromatography.
Note: Permanganate method involved bubbling air through a liquid trap, then adding permanganate and titrating.

METHODS

Air Sampling

In 1986, the study investigators selected 15–20 jobs in each plant to be monitored. Some jobs were selected for monitoring because they had a relatively large number of air samples that were available historically (greater than 10) and monitoring would increase the confidence in the accuracy of the historical measurements. Other jobs were selected because they had very few samples that were available historically. Two types of jobs were also selected because of expected high variability of exposures: maintenance and shipping and receiving operators (loaders).

All measurements in a plant were taken over a one-week time period in 1986. The measurements were personal samples placed on the shoulder of the study subjects at the start of the work shift. Measurements were taken for at least six hours. The investigators used NIOSH Sampling and Analytical method S156M. Briefly, this method calls for collection of the contaminant on SKC charcoal tubes, desorption via methanol, and analysis by gas chromatography with a nitrogen phosphorus detector.[9] The pumps were pre and post calibrated every day. The same industrial hygienist and industrial hygiene technician collected the samples at all of the plants following the same written protocol. All samples were analyzed by one laboratory. A spiked and blank sample was generated for every ten measurements or at least every sample day.

Originally there had been no plan to conduct concurrent personal sample measurements with the companies. Upon entering seven of the eight plants, the investigators learned that the industrial hygiene staff would be collecting concurrent measurements on the same workers. As a result, there were several major differences between the sampling protocol of the study investigators and those followed by the individual plants. At each plant the sampling and analytical method was that used by the plant at the time of measurement.

The sampling methods were: (a) charcoal tubes (Plants 3 and 6); (b) passive monitors (Plants 1, 2, 4, 5, and 6); and (c) porous polymer tubes (Plant 7). One plant (Plant 6) collected the samples using charcoal tubes for two days and a passive monitor for four days. (The actual method used by each plant was not obtained from the companies due to the ad hoc nature of the situation.)

There were other differences as well. The duration of the measurements by the plants was not always the same as that of the authors' measurements. One plant collected samples on about half of the workers measured by the study investigators. Other companies did not measure all the jobs measured by the study investigators and no concurrent measurements were collected in Plant 8. Information available indicates that analysis was done by five of the seven companies by on-site laboratories. No information was available on which laboratories the other two companies used.

Statistical Analysis

Agreement between the study and plant measurements was examined both by plant and by sampling method. Paired t-tests and sign tests were used to compare the means of the study and plant data. Average relative differences were calculated by dividing the difference between the plant and study investigators' results by the study results. Some of the plant measurement results were reported as between < 0.1 and 0.2 ppm. For these values we used the method recommended by Hornung and Reed, for dealing with measurement values below the limit of detection.[10] Other results were reported to be below these values (e.g., 0.04 ppm). These values were used at face value.

Analyses were conducted with all measurements and with only those measurements that exceeded 0.2 ppm to ensure that any disagreement found was not simply due to the levels being in the nondectable range. Analyses were also conducted using only measurements > 2.0 ppm, because of the OSHA PEL of 2 ppm.[8] Measurements that did not have a concurrent measurement taken by the company were excluded from the analyses.

To explore the difference due to possible chemical interferences or other conditions related to operations, comparisons where the study measurements were > 0.2 ppm were made by grouping jobs with similar functions (i.e., lab, tank farm, supervision, maintenance, fiber production, AN production, and resins production). Spearman correlations were used to determine how the ranking of the two sets of measurements compared.

RESULTS

A total of 354 measurements were taken by the study investigators on 142 jobs. The jobs selected covered most of the departments in the plants using or handling AN, and generally were the highest exposed jobs in those departments. Although the goal of the investigators was to monitor each job three times, this procedure was not followed for the administrative workers. Instead, three jobs were monitored once, resulting in the disproportionate number of administrative jobs.

Efforts were concentrated on the shipping and receiving, maintenance, and production jobs (Table II). The percentage of maintenance jobs appears lower than the other two groups. The

TABLE II

Types of jobs monitored, by plant (number of jobs monitored in 1986/number of jobs in the epidemiological study in 1983)

	Plant								
Type of job[A]	1	2	3	4	5	6	7	8	All
Administrative	3/6	2/4	3/3	2/6	3/10	3/6	1/4	2/12	19/51
Quality control	1/9	1/6	1/4	1/2	1/6	1/10	3/10	1/8	10/55
Supervisors[B]	1/15	1/9	1/12	1/18	1/33	2/21	0/32	3/28	10/168
Environmental control	0/6	2/13	1/0	1/1	1/4	0/4	0/3	0/9	5/40
Shipping & receiving	1/6	1/5	2/0[C]	1/8	1/1	5/8	2/6	1/6	14/40
Maintenance	3/35	2/14	2/4	2/11	2/8	2/10	2/31	3/37	18/150
AN using production Processes	6/12	8/6	4/16	10/31	8/43	9/19	9/26	10/24	64/177

[A]Does not include other support jobs, such as labor, utilities (2 jobs monitored in 1986), housekeeping, research & development (1 job monitored in 1986), engineering (3 jobs monitored in 1986), etc.

[B]Includes jobs of foremen and higher in the supervisory chain in the quality control lab, maintenance, shipping and receiving, and production.

[C]The function of shipping and receiving was done by AN production workers and is included in AN using production processes.

proportion of jobs monitored was similar to those of the other two jobs when compared to the personnel records of the maintenance workers. In the epidemiological study, however, the maintenance job titles were renamed based on the amount of time spent in the AN units. Thus, in one plant, there may be five different types of mechanics: mechanic/no AN, mechanic/5 percent in AN, mechanic/25 percent in AN, mechanic/50 percent in AN, and mechanic/100 percent in AN. This procedure substantially increased the number of maintenance jobs.

Most of the jobs selected by the study investigators (63%) had not been monitored between 1980 and 1983 by the companies (Table III). This may have been in part because of the low levels of exposure. The large number of jobs that were monitored in 1986, but were not in the epidemiologic study in 1983, was due to the fact that 1) the personnel records were not abstracted until after the monitoring, so that the investigators did not know what jobs were in the epidemiologic study; 2) three different unexposed administrative jobs were monitored in each plant that were combined into a single "job" in the epidemiologic study; and 3) in some of the plants a single job title (e.g., operator) was composed of several jobs (e.g., reactor operator, purification operator, etc.). However, 57 jobs were nonexistent in 1983, as indicated by the total number of estimates developed for the epidemiological study. Of the jobs that did exist at that time, almost 75 percent had exposures < 0.5 ppm, and only 4 percent had an estimated exposure level of > 1.0 ppm. Levels appeared in general to have decreased in 1986: 80 percent of the jobs measured had geometric mean exposures of < 0.5 ppm. About 4 percent of the jobs, however, had levels < 2.0 ppm. These jobs were electricians in Plant 1 (2.61 ppm, n = 2), the reactor operator in Plant 1 (3.58 ppm, n = 4), the purification operator in Plant 3 (2.79 ppm, n = 1), the truck loader in Plant 6 (5.61 ppm, n = 2) and the production coordinator in Plant 6 (5.07 ppm, n = 1).

TABLE III

Distribution of jobs monitored, by number of historical measurements, 1986 measured geometric mean and 1983 estimated level

	Plant								
	1	2	3	4	5	6	7	8	Total
# measurements 1980–1983									
0	10	19	15	8	9	13	10	6	90
1–10	0	0	0	2	3	3	2	0	10
> 10	4	3	0	9	3	4	5	14	42
									142
1986 Geometric mean									
< 0.1	2	12	3	5	10	1	7	13	53
0.1–0.49	7	7	8	10	4	10	10	5	61
0.5–0.99	1	2	2	2	1	5	0	2	15
1.0–1.99	2	1	1	2	0	2	0	0	08
> 2	2	0	1	0	0	2	0	0	05
									143
Estimated[A] 1983 level									
< 0.1	1	6	1	2	1	4	5	3	23
0.1–0.49	5	1	1	5	7	3	6	13	41
0.5–0.99	5	0	1	8	1	1	0	2	18
1.0–1.99	1	0	0	0	1	1	0	0	3
									85

[A]Estimated in the epidemiological study.

The concurrent measurements using charcoal tubes showed good agreement, having a difference of 14 percent at a mean of 1.12 ppm for study samples (Table IV). The difference between the measurement results from these two sets of data was not statistically significant. They were highly correlated with the company data (r = 0.97). The comparison of the study measurements and those collected by the passive monitors, however, found a significant difference of 21 percent at a mean of 0.92 ppm, although the correlation between these two sets of data was high (r = 0.98). This difference indicates a systematic bias such that the study results were consistently higher than the plant results.

The comparison with the porous polymer tubes showed a somewhat unusual picture. There was a poor linear relationship between these two sets of data (r = −0.05), but the average of the differences was 0.0 and the difference between the two data sets was not statistically significant. When only study measurements that exceeded 2 ppm were analyzed the measurements from both the charcoal tube and the passive monitor exhibited high agreement with the study measurements (average relative difference = 6 and 27%; r = 0.99 for both; n = 5 and 14, respectively [not shown]). There were no values > 2 ppm for the porous polymer tubes.

When the individual plants were evaluated, significant differences were found in five of the plants (1, 2, 4, 5, 6) using the sign test and in two plants (1 and 4) using the t-test (Table V). In only one plant, however, did the difference exceed 50 percent (Plant 5), the level of variability considered acceptable by OSHA for sampling and analytic techniques for acrylonitrile.[8] The correlations were high for five of the six plants (r > 0.95) (1, 2, 4, 5, 6). The polymer porous method described above was used solely by Plant 7. Those measurements correlated poorly with the study measurements. For Plant 3 the correlation between the two sets of measurements was 0.85 when measurements below 0.2 ppm were excluded.

When the agreement was evaluated by job function (regardless of sampling method) the lab, tank farm, supervisory, and fiber production jobs all showed high agreement (r > 0.95) and relative mean differences of ≤ 50 percent (not shown). The correlation between the measurements on maintenance workers was 0.67 but the relative difference was 22 percent. For measurements on AN production workers (Plants 2, 3, 6) the correlation was lower (r = 0.49) and the mean relative difference was −93 percent. The measurements taken in the resins operations (Plant 7 and subsets of Plants 3 and 6) were poorly correlated (r = −0.27) but the mean difference was 21 percent.

TABLE IV
Summary of statistical analysis of concurrent measurement data, by method

Method used by plant (plant no.)	# of pairs	Study mean (ppm)	Range of study measurements (% > 0.2)	Plant mean (ppm)	Means of differences[A] (SD)	Relative difference[B] (%)	P-value for paired t-test	P-value for paired sign test
Charcoal tube (3, 6)	73	1.12	0.01–35.4 (70)	1.27	−0.16 (0.93)	−14	0.16	0.32
Passive monitor (1, 2, 4, 5, & 6)	157	0.92	0.01–35.40 (52)	0.73	0.19 (0.96)	21	0.01	< 0.01
Porous polymer (7)	34	0.17	0.01–0.78 (24)	0.17	0.00 (0.24)	0	0.95	0.32

[A]Means of differences calculated as ×diff = ×study − ×plant.
[B]Relative difference calculated as ×diff ÷ ×study.

DISCUSSION

The purpose of this article was to highlight a frequently encountered occurrence when performing exposure assessment in epidemiological cohort studies, that is, that of having measurement data from different work sites. It described a procedure used to evaluate the amount of exposure misclassification.

The authors took advantage of data collected for a different purpose to compare how measurements taken concurrently on the same person compared using different sampling and analytical techniques. The goal of the investigation was not to accept or reject the measurements, rather it was to determine how bad the disagreement was and the situations under which it occurred.

In fact, the authors were quite surprised that the agreement was so high in most comparisons. Only the polymer porous method showed poor correlation, although the overall difference between the means of the two measurement results was essentially zero. We investigated this plant's method further, including reviewing the method validation work, but could find no reasons for this lack of comparability. The plant had originally developed this method because the conditions in the plant did not appear to generate valid results when charcoal tubes were used. The difference may have been due to the low exposure levels: only 24 percent (n = 9) of our measurement results exceeded 0.2 ppm.

Low levels also appeared to have affected the other two plants with poor agreement. For Plant 3 the correlation between the two sets of measurements was 0.38 for all measurements and 0.85 when measurements below 0.2 ppm were excluded. In Plant 5, the other plant with poor agreement, all but one measurement

TABLE V
Summary of statistical analysis of concurrent measurement data, by plant

Plant No. (method for plant)	# of pairs	Study mean	Range of measurements (% > 0.2)	Plant mean	Mean of differences (SD)	Relative difference (%)	P-value for paired t-test	P-value for paired sign test
1 (PM)	35	1.21	0.01–13.61 (71)	0.80	0.41 (1.07)	34	0.03	0.04
2 (PM)	47	0.35	0.01–3.26 (28)	0.25	0.10 (0.23)	29	< 0.01	0.01
3 (CT)	42	0.45	0.01–2.8 (62)	0.63	−0.17 (1.17)	−38	0.35	0.11
4 (PM)	14	0.59	0.02–2.73 (57)	0.45	0.15 (0.23)	25	0.04	0.02
5 (PM)	18	0.13	0.01–1.31 (94)	0.46	−0.33 (1.10)	−250	0.22	0.01
6 (PM)	43	1.74	0.02–35.40 (83)	1.40	0.35 (1.31)	20	0.09	0.02
6 (CT)	31	2.02	0.02–35.40 (13)	2.15	−0.13 (0.44)	6	0.10	0.09
7 (PP)	34	0.17	0.01–0.78 (24)	0.17	0.00 (0.24)	0	0.95	0.30

Note: PM = Passive Monitor; CT = Charcoal Tube; PP = Porous Polymer.

were below 0.2 ppm. Furthermore, when only measurements from all plants were included that exceeded 2 ppm by the study method both the charcoal tube and the passive monitor exhibited high agreement with the study method (average relative difference = 6 and 27 percent; r = 0.99 for both; n = 5 and 14, respectively).

It was unfortunate that many of the exposure levels were so low, but many of the jobs were selected because only a few samples had been collected for that job. Generally only a few samples had been collected because the plants deemed those jobs to have less exposure. Most of the high exposure jobs were monitored at the time of study. A variety of departments were selected to ensure that a range of environmental conditions (e.g., a variety of chemicals, indoors and out; controlled and uncontrolled; steady state and peaks) were present. Similar findings of the effect of measurements near the limit of detection have been reported in a field comparison of passive samplers for monomethylhydrazine and of passive dosimeters and charcoal tubes measuring styrene.[11-12]

Thus, the measurement data from all the seven plants in the study were taken at face value. Investigators encountering changes in sampling and analytical methods in a single plant have taken different approaches. Some authors of silica studies used a conversion factor to make the sample measurements comparable, while others excluded measurements that had been collected using a different sampling and analytical technique.[13-14] In a study of ethylene oxide workers, passive monitor data were discarded due to differences in the variability of that method compared to the sorbent tube method.[15] Hallock et al. used sampling data from only two of the three plants in a study evaluating exposure to machining fluids, due to differences based on an ANOVA analysis.[16]

Several data sets exist that evaluated measurements taken on the same person concurrently to compare different sampling techniques. These could be used for comparison to the data collected in this study. Some of these comparisons involve particulate sampling and analytical methods and one must be cautious when comparing vapor and particulate sampling databases. However, it is noteworthy that both particulate and vapor methods compared in laboratory environments often show much closer agreement than concurrent measurements conducted in true field conditions.[11,17-18]

In a study of cotton dust exposures in nontextile cotton facilities, agreement was evaluated between the standard cotton dust sampler, the vertical elutriator (VE), and a smaller battery-operated vertical elutriator. The OSHA Cotton Dust Standard allowed use of equivalent samplers if side-by-side tests showed that the air concentration via the test method was within ±25 percent of the VE air concentration in 95 percent of the side-by-side tests conducted. Tests conducted in field environments (e.g., cotton ginning facilities, cotton waste utilization) showed much lower agreement (97 of 153 sample-pairs were between between ±25 percent) than tests conducted in a laboratory setting (USDA model card room), where 27 of 27 sample-pairs were within ±25 percent.[17-18] This drop in agreement between the two methods during the field tests is similar to what Olsen et al. found when evaluating organic solvent samplers, "... the error of field measurements was found to exceed the error determined under well controlled laboratory conditions."[11]

Most evaluations of sampling and analytical techniques are conducted in laboratories under tightly controlled conditions. Laboratory environments enable the investigators to maintain better consistency in chemical concentrations, humidity, air velocity, sampler inlet orientation, and so on. In field environments, investigators who conduct personal monitoring of mobile employees are often faced with inconsistent conditions. These changing conditions may include the chemical concentration, variable air velocity, and humidity levels that vary drastically from one process area to another. Chemical plants provide a variety of such changes. For example, an assistant operator may spend two hours of the shift in the control room with consistent humidity, temperature, and low ambient air velocity. This same person may also make three or four trips to check on instruments located in outdoor production areas. Finally, he or she may spend several hours in locations where processing equipment can generate high temperatures and either very high or very low humidity. Thus, the excellent agreement often obtained in the laboratory environment should not necessarily be expected in a field environments.

In an ideal study that would allow a confident interpretation of concurrent measurement, several conditions would be necessary. For the concurrent measurement data evaluated in this study, however, and for epidemiological exposure assessment efforts being conducted across many sites most of these conditions were not and will not be met. The conditions in the study described here included a) different people collected samples for each plant, b) different analytical laboratories were used to analyze the AN samples, and c) different sampling and analytical methods were used. These factors are due in part to the fact that each plant IH conducted his or her evaluation independently of other plant IHs. For example, the distance separating study and plant sampling trains may not have been consistently maintained at different plants (no records were available indicating approximate distances separating the samples). Another source of difference may have been the presence of different analytical interferences, which would affect the plant data differently because of the different substances and conditions present. It was important, however, to maintain these differences because they were incorporated in the historical sampling results.

Until the last few years, few data sets existed that compared both laboratory and field-generated performance characteristics for the same sampling and analytical methods. Even fewer data sets are available that compare two different sampling techniques simultaneously measuring the same chemical in field environments. The authors were unable to find any published reports of comparisons of different sampling methods used by different industrial hygienists and analyzed by different laboratories, as was done in this study. Thus, there is no guidance from the

published literature as to the level of disagreement acceptable. In one sense, however, the amount of misclassification acceptable to investigators may vary from study to study, depending on the magnitude of the expected level of disease risk. Higher disease risks may tolerate higher levels of misclassification.

The needs of the epidemiological study required that the study investigators use the historical monitoring data. The purpose of this study then, was not to determine which data to discard, but rather how the lack of consistent measurement might affect the interpretation of the epidemiological data. We concluded that while it was a source of misclassification, it was probably small compared to other sources of error. The authors of this evaluation believed that comparing the two data sets even with the known limitations of the data collection was preferable to either using the data as is without understanding their limitations or discarding the entire data set with the result of having no available personal monitoring data.

It is likely that other occupational safety and health researchers will face similar dilemmas in the future. It is hoped that the data presented here will provide some guidance for other researchers.

CONCLUSIONS

When one considers the many variables associated with this concurrent measurement data set, the results obtained from comparing the concurrent measurements are reasonable. Because of these many limitations and the reasonableness of the data in light of these limitations, there was insufficient basis to make adjustment to any of the plant data. No corrections were therefore made to any of the plant data.

It is recommended that future epidemiological studies of multiple work sites conduct a formal evaluation of the measurement data by collecting concurrent measurements with the companies. Failure to do so could result in exposure estimates being developed from different measurement scales. This is not a problem as long as the subjects in the plants are analyzed separately. The advantage, however, of multisite epidemiological studies is that the subjects from the various sites can be pooled to increase power to find statistical significance. Having estimates on different measurements scales could cause differential or nondifferential bias. Such bias would decrease the ability to find an association.

ACKNOWLEDGMENTS

The authors extend their thanks to NIOSH and NCI personnel who provided guidance or assisted with various aspects of this evaluation: Aaron Blair, Marilyn Fingerhut, Manuel Gomez, Dave Brown, Charles Mueller, Ken Wallingford, Greg Piacitelli, Eric Esswein, Marianne Fleckinger, and Karen Frost. We extend our thanks to the plant and union representatives who assisted with the study protocols and the plant visits, and to the employees who were interviewed and/or wore sampling pumps during the study. We also express our gratitude to the AN Advisory Panel (Dr. Robert Harris, Dr. Roy Shore, Dr. Richard Monson, Dr. Edward Bresnick, Dr. Carol Rice, and Dr. Kathy Hammond) for their expertise and patience.

REFERENCES

1. Stewart, P.A.; Lees, P.S.J.; Francis, M.F.: Quantification of Historical Exposures in Occupational Cohort Studies. Scan J Work Environ Health 22:405–414 (1996).
2. Rice, C.; Harris, R.L.; Lumsden, J.C.; et al.: Reconstruction of Silica Exposure in North Carolina Dusty Trades. Am Indus Hyg Assoc J 45(10):689–696 (1984).
3. Blair, A.; Stewart, P.A.; Zaebst, D.; et al.: Mortality of Industrial Workers Exposure to Acrylonitrile. Scand J Work Environ Health 24 (Suppl 2):25–41 (1998).
4. Stewart, P.A.; Lemanski, D.; White, D.; et al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. I. Job Exposure Profiles: A Computerized Data Management System. Appl Occup Environ Hyg 7(12):820–825 (1992).
5. Stewart, P.A.; Triolo, H.; Zey, J.N.; et. al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. II. A Computerized Exposure Assessment Program. Appl Occup Environ Hyg 10(8):698–706 (1995).
6. Stewart, P.A.; Zey, J.N.; Hornung R.F.; et al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. III. Evaluation of Exposure Assessment Methods. Appl Occup Environ Hyg 11(11)1312–1321 (1996).
7. Stewart, P.A.; Zaebst, D.; Zey, J.N.; et al.: Exposure Assessment for a Study of Workers Exposed to Acrylonitrile. Overall Methods. Scand J Work Environ Health 24 (Suppl 2):42–53 (1998).
8. Code of Federal Regulations, Parts 1900 to 1910 (Labor). Occupational Safety and Health Administration (OSHA). 29 CFR 1910.1045 OSHA Standard for Occupational Exposure to Acrylonitrile. U.S. Government Printing Office, Washington, DC (1978).
9. National Institute for Occupational Safety and Health: NIOSH Sampling and Analytical Method 5156—Adsorption on Charcoal, Desorption with Methanol, Followed by GC NPD Analysis. NIOSH Manual of Analytical Methods, NIOSH Pub #84–100. (The Acrylonitrile Method was published in a 1985 supplement). NIOSH, Cincinnati, OH (1984).
10. Hornung, R.; Reed, L.: Estimation of Average Concentrations in the Presence of Nondetectable Values. Appl Occup Environ Hyg 5:46–51 (1990).
11. Olsen, E.; Laursen, B.; Vinzents, P.S.: Bias and Random Error in Historical Data of Exposure to Organic Solvents. Am Indus Hyg Assoc J 52(5):204–211 (1991).
12. Rose-Pehrsson, S.L.; Wyatt, J.R.; Brenner, K.P.; et al.: Laboratory Development and Field Evaluation of a Passive Sampling Device For Monomethylhydrazine in Ambient Air. Am Indus Hyg Assoc J 55(2)149–162 (1994).
13. Sheehy, J.W.; McJilton, C.E.: Development of a Model to Aid in Reconstruction of Historical Silica Dust in the Taconite Industry. Am Indus Hyg Assoc J 48(11):914–918 (1987).
14. Eisen, E.A.; Smith, T.J.; Wegman, D.H.; et al.: Estimation of Long Term Dust Exposure in the Vermont Granite Sheds. Am Indus Hyg Assoc J 45(2):89–94 (1984).
15. Hornung, R.W.; Greife, A.L.; Stayner, L.T.; et al.: Statistical Model for Prediction of Retrospective Exposure to Ethylene Oxide in an Occupational Mortality Study. Am J Indus Med 25:825–836 (1994).
16. Hallock, M.F.; Smith, T.J.; Woskie, S.R.; et al.: Estimation of Historical Exposures to Machining Fluids in the Automotive Industry. Am J Indus Med 27:621–634 (1994).

17. Zey, J.N.; Piacitelli, G.M.; Jones, W.G.; et al.: Field Evaluation of an Alternative Cotton Dust Sampler. Presented at the 1983 American Industrial Hygiene Conference. May 22–27, 1983. Abstract No. 180.
18. Zey, J.N.: Cotton Industry Survey Conducted by NIOSH. In: Annals of the American Conference of Governmental Industrial Hygienists (ACGIH), Volume 2, Agricultural Respiratory Hazards, pp. 37–44. Cincinnati, OH (1982).
19. Van-Den-Hoed, N.; Van Asselen, O.L.J.; Van Dongen, J.P.C.M.: Replicate Side-by-Side Field Comparison of 3M Diffusive Samplers Versus Charcoal Tube Samplers for Styrene. Am Indus Hyg Assoc J 48(3):252–256 (1987).